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Rolling Stock Scheduling with Maintenance Requirements at the Chinese High Speed Railway

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ROLLING STOCK SCHEDULING WITH MAINTENANCE REQUIREMENTS AT THE CHINESE HIGH-SPEED RAILWAY

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1. Introduction

Chinese High-speed Railway

◻ Construction of high-speed railway network

- By September of 2016 the HSR network was already approximately 22,000 km in length, accounted for more than 60% of the world's high speed rail track
- plans to increase this further to 30,000 km by 2020 and to 38,000 km by 2025

◻ Rolling stock

- The HSR has a fleet of 2,600 trains. On any given day approximately 2,300 of these are in operation and collectively cover around 4,500 timetabled services
- All rolling stock units must be regularly maintained to ensure the safety of the system.24 depots are scattered throughout the HSR network

1. Introduction

Rolling stock schedule

- The timetable for the HSR is revised annually (however, there may also be slight adjustments during peak periods and holidays, e.g., Chinese New Year).
- Usually, when the timetable requires modification, all dispatchers meet to devise a new rolling stock schedule.

Problem

As the rolling stock planning is mainly a manual process in China, it is often difficult to quickly obtain an optimal rolling stock schedule that covers the timetable and which also adheres to the rolling stock maintenance requirements.

2. Problem descriptions

The rolling stock scheduling problem involves assigning so-called *compositions* to a set of timetabled services.

- Rolling stock unit: 8 cars
- (de) coupling can take place at depot and stations (with depot track)

Figure 1 Examples of train compositions

2. Problem descriptions

The services specified in the timetable a defined by a set of *trips*. Each *trip* specifies the movement of a train between two stations at a specific time. And also a minimal number of units required on each trip is forecasted.

Type AL and B are used to serve these trips.

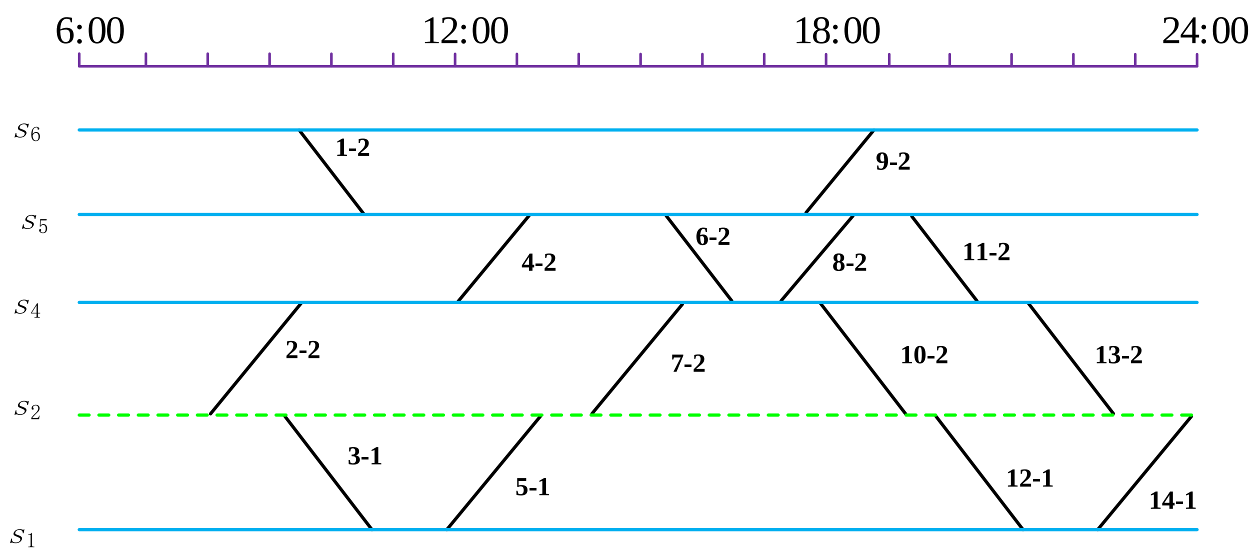
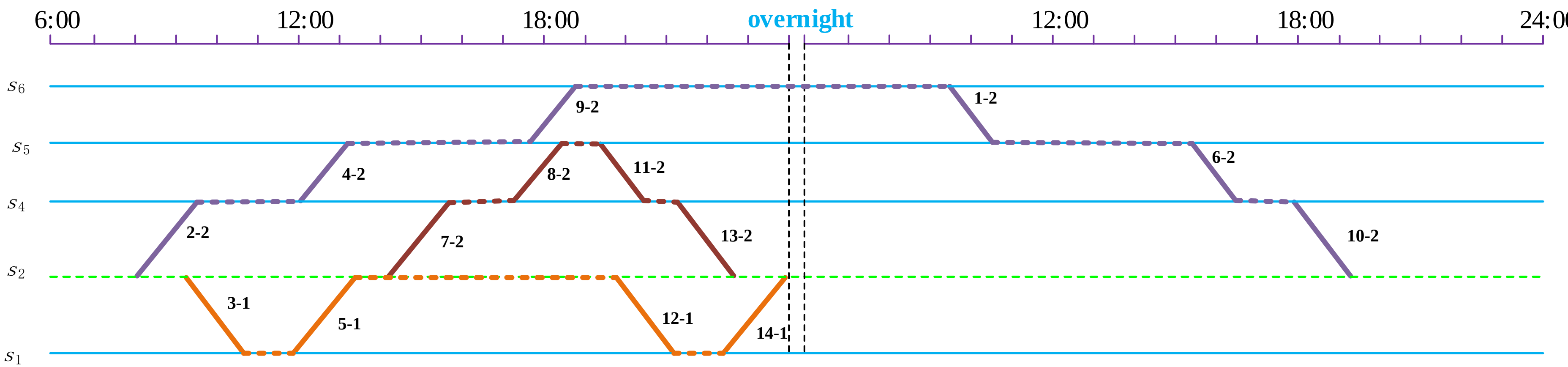


Figure 2 Illustration of the timetable

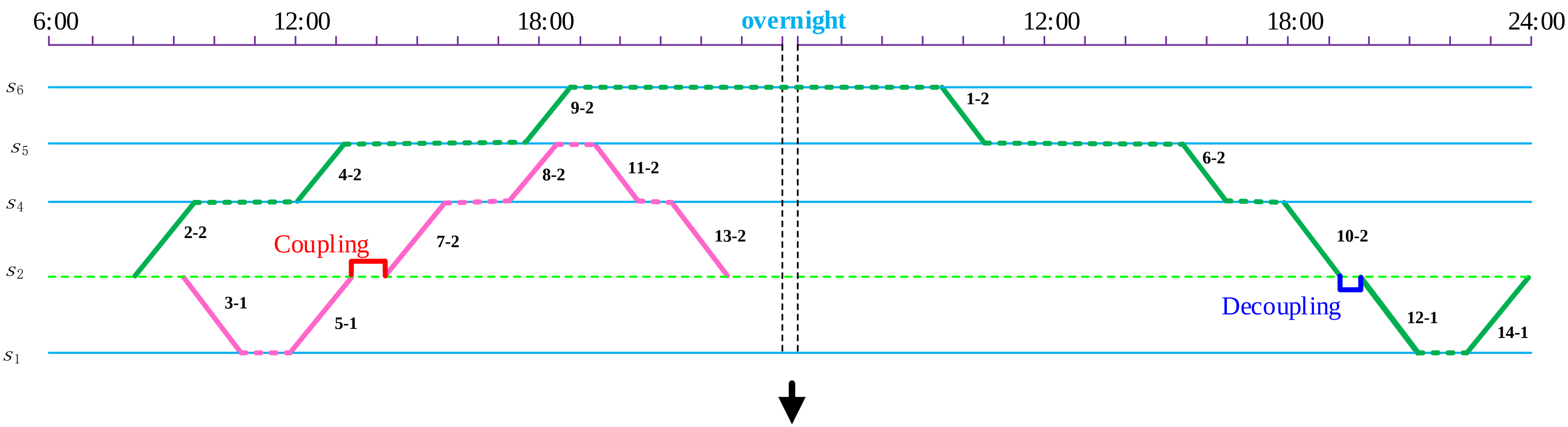
2. Problem descriptions



Circulation path	Possible Rolling stock composition
depot····· 2 — 4 — 9 Overnight 1 — 6 — 10 ·····depot	2 units of type: AL 2 units of type: B
depot····· 7 — 8 — 11 — 13 ·····depot	2 units of type: AL 2 units of type: B
depot····· 3 — 5 — 12 — 14 ·····depot	1 units of type: B 2 units of type: B 2 units of type: AL

Figure 3 Schedule 1

2. Problem descriptions



Circulation path	Possible rolling stock composition
Overnight Decoupling depot····· 2 — 4 — 9 1 — 6 — 10 12 — 14 ·····depot depot····· 2 — 4 — 9 1 — 6 — 10 ·····depot depot····· 2 — 4 — 9 1 — 6 — 10 — 12 — 14 ·····depot	2 units of type: B
Coupling depot····· 3 — 5 7 — 8 — 11 — 13 ·····depot depot····· 3 — 5 — 7 — 8 — 11 — 13 ·····depot depot····· 7 — 8 — 11 — 13 ·····depot	2 units of type: B

Figure 4 Schedule 2

2. Problem descriptions

When considering maintenance, a trip sequence can only be assigned to a unit if the time and mileage consumption of the trip sequence is less than the remaining time and mileage of the unit in question.

We focus on level one maintenance (or daily maintenance). This stipulates that all rolling stock units undergo a maintenance check every two days, or when the accumulated mileage exceeds 5,500km.

The rolling stock scheduling problem that we consider therefore involves not only determining the best composition for each trip, but also deciding how to assign compositions in such a way that the trip sequences assigned to each individual unit do not violate the maintenance requirements specified.

3. Two-stage approach

Decompose the problem into two stages:

- a conventional flow based model： ignoring maintenance, to obtain multiple rolling stock schedules.
- a series of assignment problems：considering maintenance, using the solutions found in the first stage.

Assumptions:

- The timetable is known before scheduling any rolling stock units.
- Not all stations can be used for overnight parking.
- Dead heading units to start trips is possible.
- All rolling stock units must go through a coupling and a decoupling procedure at the start and end of every trip sequence.

3. Two-stage approach

Approach:

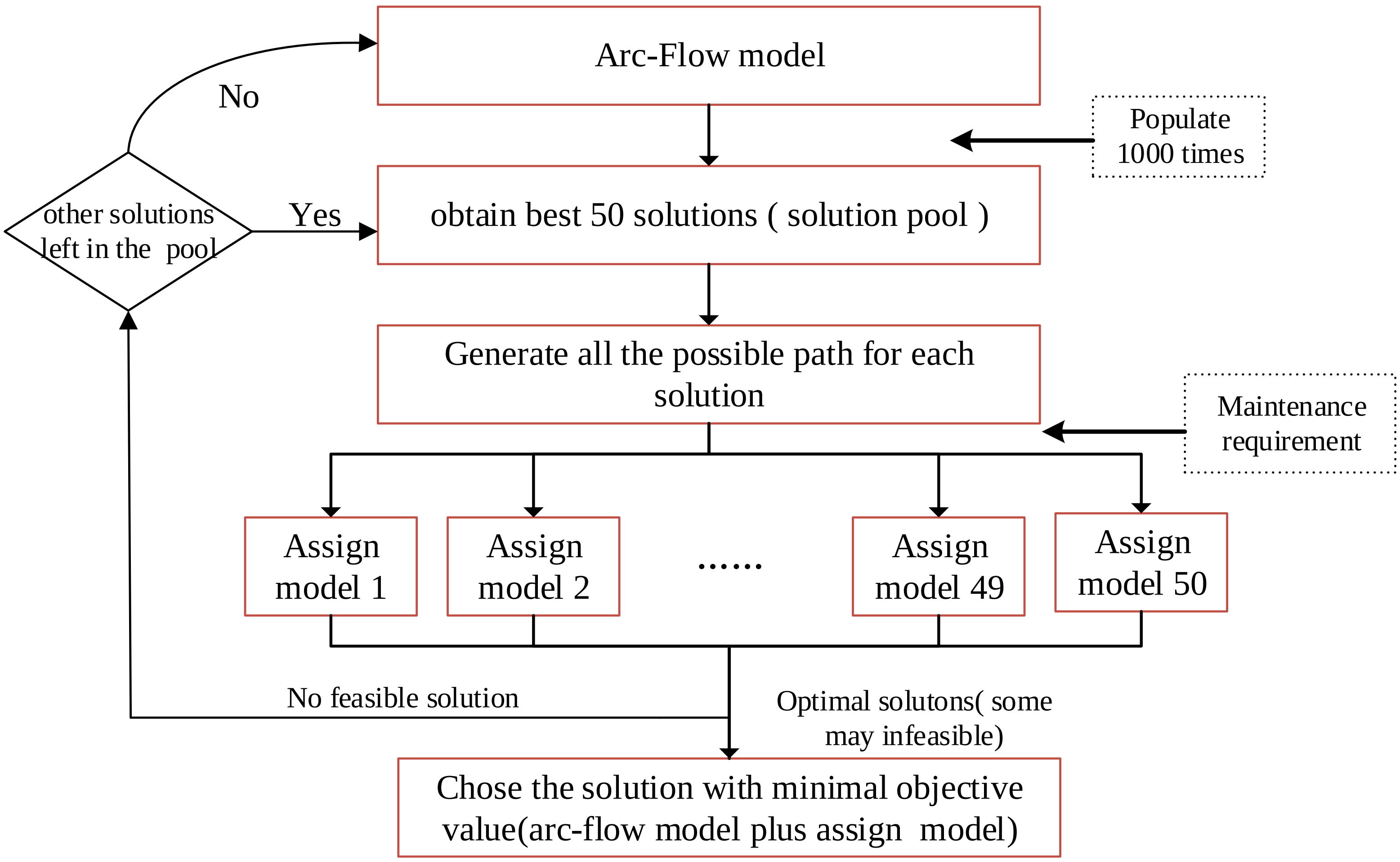


Figure 5 Flow diagram for the proposed approach

3. Two-stage approach

Arc-flow model:(Haahr , Nielsen)

Objective:

min: the combined operational cost + the shunting cost + depot imbalance penalties

+total deadhead mileage + the total overnight time

$$\min z = \sum_{t \in T} \sum_{c \in C} operCost_c^t \bullet y_c^t + \sum_{r \in Cnn} \sum_{c \in C} \sum_{c' \in C} changeCost_{c,c'}^r \bullet X_{c,c'}^r + \sum_{p \in P} \sum_{d \in D} penEod \bullet i_d^p + emptyMileage + overTime$$

Subject to:

(1) Trip Uniqueness

$$\sum_{c \in C} y_t^c + \sum_{c \in C} y_{t'}^c = 1 \quad \forall t \in oneT, t' \in twoT$$

$$\sum_{c \in C} y_t^c \leq 1 \quad \forall t \in emptyT : \mathrm{A}_t, \mathrm{B}_t \notin D$$

3. Two-stage approach

Arc-flow model:

Subject to:

(2) Flow Feasibility

$$\sum_{\substack{r \in Cnn: \\ s_r = t}} \sum_{c':(c,c') \in C^r_{c,c'}} X^r_{c,c'} = y^c_t \qquad \forall t \in T : A_t, B_t \notin D, c \in C$$

$$\sum_{\substack{r \in Cnn: \\ t_r = t}} \sum_{c':(c',c) \in C^r_{c',c}} X^r_{c',c} = y^c_t \qquad \forall t \in T : A_t, B_t \notin D, c \in C$$

(3) Depot Inventory

In order to precisely monitor the inventory levels, the number of rolling stock units of type $p \in P$ that are (de)coupled to the composition at connection $r \in Cnn$ must be determined.

$$v1^p_r = \sum_{c \in C} \sum_{c':(c,c') \in C^r_{c,c'}} X^r_{c,c'} \bullet couple^p_{c,c'} \quad \forall r \in Cnn, p \in P$$

$$v2^p_r = \sum_{c \in C} \sum_{c':(c,c') \in C^r_{c,c'}} X^r_{c,c'} \bullet decouple^p_{c,c'} \quad \forall r \in Cnn, p \in P$$

3. Two-stage approach

Arc-flow model:

Subject to:

(3) Depot Inventory

$$storage_{p,d}^{time} = bod_d^p - \sum_{\substack{r \in Cnn: \\ B_{s_r} = d, \\ tCoupling_r \leq time}} v1_r^p + \sum_{\substack{r \in Cnn: \\ A_{t_r} = d, \\ tDecoupling_r \leq time}} v2_r^p + \sum_{\substack{r \in Cnn: \\ s_r, t_r \in meT, \\ tDecoupling_r \leq time}} g_{r,p}^d - \sum_{\substack{r \in Cnn: \\ s_r, t_r \in meT, \\ tCoupling_r \leq time}} h_{r,p}^d \qquad \forall time \in Time, p \in P, d \in D$$

Note: here the used rolling stock units are divided into two parts: units that are (de)coupled at the depot and those that are (de) coupled at stations. which are not necessary for the model, but help us to identify the corresponding depot of (de) coupled units.

3. Two-stage approach

Arc-flow model:

Subject to:

(4) Depot Inventory-*additional*

$$\sum_{d \in D} g_{r,p}^{d} = v2_{r}^{p} \qquad \forall r \in Cnn : s_r, t_r \in meT;\, p \in P$$

$$\sum_{d \in D} h_{r,p}^{d} = v1_{r}^{p} \qquad \forall r \in Cnn : s_r, t_r \in meT;\, p \in P$$

$$\sum_{d \in D} h_{r,p}^{d} \le 1 \qquad \forall r \in Cnn : s_r, t_r \in meT;\, p \in P$$

$$\sum_{d \in D} g_{r,p}^{d} \le 1 \qquad \forall r \in Cnn : s_r, t_r \in meT;\, p \in P$$

3. Two-stage approach

Trip Sequence Assignment MIP:

Objective:

min: the activation costs of the units

$$\min z = \sum_{l \in L} \sum_{roll \in Rolling} j_{roll}^{l} \bullet assCost_{roll}$$

Subject to:

There are two main types of constraints in the MIP model. The first ensures that the number of rolling stock units assigned to each trip is consistent with the solution to the arc flow formulation. The second ensures that each unit receives at most one trip sequence.

$$\sum_{roll \in Rolling} \sum_{l \in L_{roll}} a_l^t \bullet j_{roll}^{l} = b_t \qquad \forall t \in meT$$

$$\sum_{l \in L_{roll}} j_{roll}^{l} \leq 1 \qquad \forall roll \in Rolling$$

3. Two-stage approach

Algorithm:

Step 1: Using the results of the arc-flow model, identify all unit flows (from depot to depot). Divide the flows into two sets: one set contains flow without composition changes outside the depot, while the other contains composition changes outside of the depot.

Step 2: For the flows without composition changes outside the depot, split each flow into individual trip sequences.

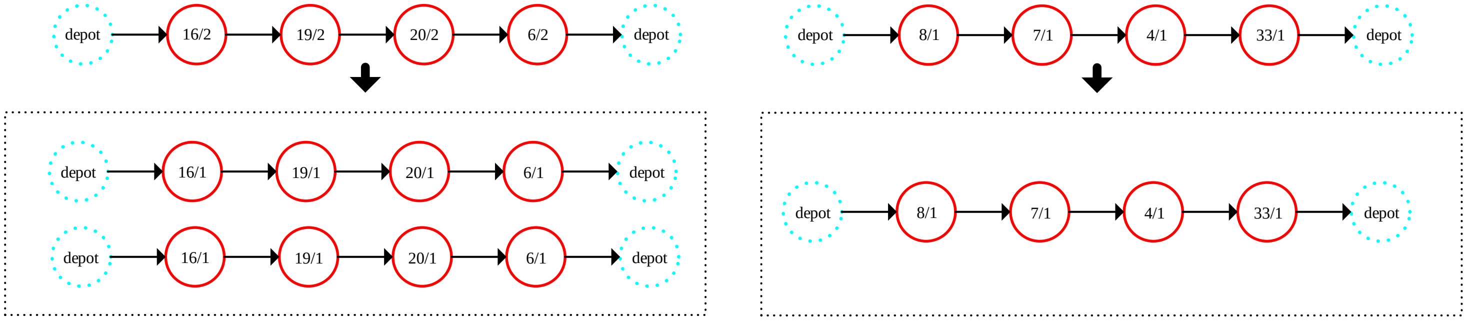


Figure 6 Illustration of flow without composition change

3. Two-stage approach

Algorithm:

Step 3: split the flows with composition changes outside the depot

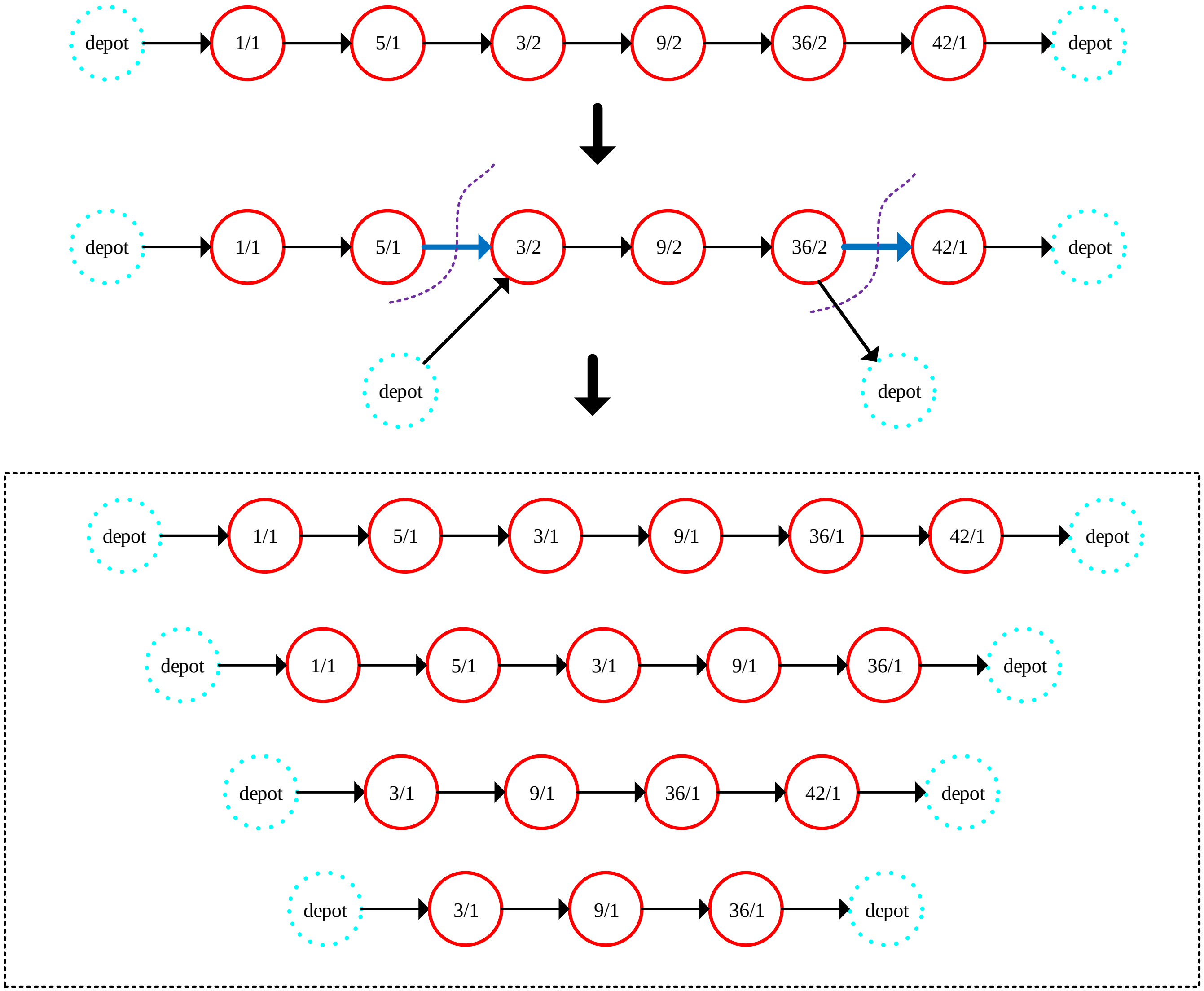


Figure 7 Illustration of flow with composition change

3. Two-stage approach

Algorithm:

Step 4: After steps 2 and 3, all the flow is represented as partial trip sequences for a single rolling stock unit. Based on the partial trip sequences, it is easy to enumerate all full trip sequences.

4. Results

Setting:

- A real-life instance provided by the Chinese High Speed Railway(Zhengzhou railway).
- 31 main stations and two depots.
- three different rolling stock types: 5 composition changes.
- a total of 91 units and 377 trips

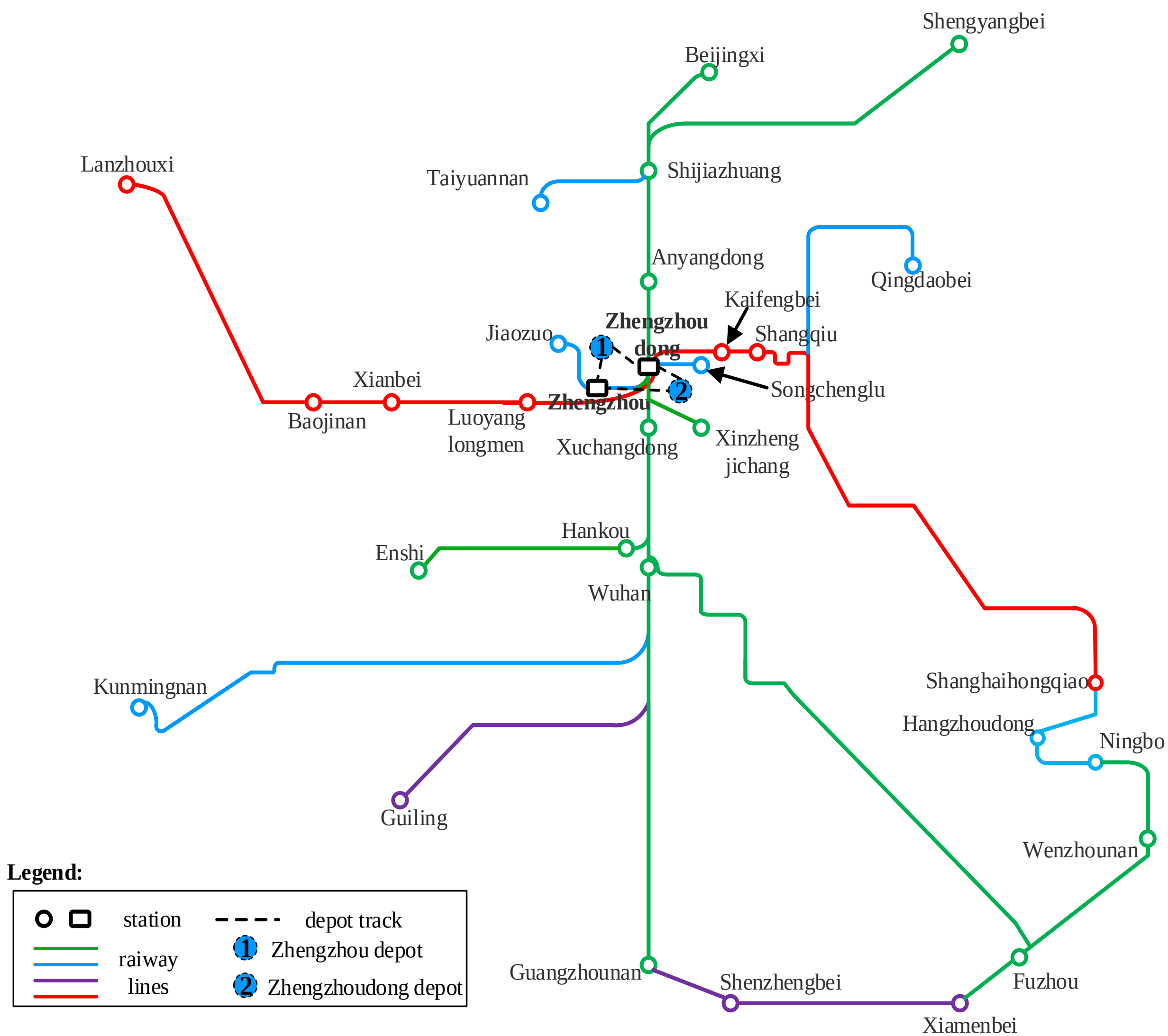


Figure 8 Sketch of China Zhengzhou Railway

4. Results

Setting:

TABLE 1 Initial location of unit types

Depot	CRH380AL	CRH380A	CRH380B
Zhengzhou	0	7	11
Zhengzhoudong	36	9	28

47 units have just finished their respective level one maintenance checks.

There are five different possible compositions are listed in Table 2.

Table 2 The compositions of rolling stock units

Composition name	Rolling stock type	Number of units
CRH380AL-long	CRH380AL	2
CRH380A-long	CRH380A	2
CRH380A-short	CRH380A	1
CRH380B-long	CRH380B	2
CRH380B-short	CRH380B	1

All parameters used in the model have been determined with the dispatchers, except for the imbalance penalty. We have set this to 100,000 to be consistent with previous work in this area.

4. Results

Schedules with and without maintenance:

51 paths in both case:

TABLE 3 Composition changes: Schedules with and without maintenance

	Coupling times	Decoupling times	Rolling stock swaps
Maintenance	2	3	10
No-maintenance	4	-	16

TABLE 4 Key statistics: Rolling stock schedules with and without maintenance

	ARL	MRL	MARL	TERL	AERL	OP	TC
Maintenance	2678.4	342	4763	3252	63.8	13	817161
No-maintenance	2679.6	565	4771	3225	63.2	13	812143
Comparison	0.0%	65.2%	0.2%	-0.8%	-0.9%	-	-0.6%

Note: The comparison is based on the maintenance row; negative percentages indicate an improvement.

TABLE5 Basic information of used rolling stock units

	Depot	CRH380AL	CRH380A	CRH380B	Utilization
Maintenance	Zhengzhou	0	0	11	61.1%
	Zhengzhoudong	16	0	24	54.8%
No-maintenance	Zhengzhou	0	1	11	66.7%
	Zhengzhoudong	16	0	23	53.4%

4. Results

Manual schedule and computational schedule(with maintenance):

Manually schedule: 57 trip sequences ; maintenance feasible
Algorithm schedule: 51 trip sequences ; maintenance feasible

TABLE 6 Key statistics: Rolling stock schedules – Algorithm vs Dispatcher

	ARL	MRL	MARL	TERL	AERL	OP	TC
Algorithm	2678.4	342	4763	3252	63.8	13	817161
Dispatcher	2435	183	4898	5291	92.8	13	870386
Comparison	10.0%	86.9%	-2.76%	-38.5%	-31.3%	-	-6.1%

- the proposed optimization method can significantly reduce the deadhead mileage:The total deadhead mileage is reduced by 2039 km (38.5%)
- the average rolling stock mileage has increased by 243.4 km (10%)

A reduction in dead head mileage and an increase rolling stock mileage both help improve the efficiency of the rolling stock schedule.

- **the 6% reduction in operating cost**: Maintaining and operating a HSR is not cheap, and a 6% reduction in operating costs results in substantial savings.

4. Results

Manual schedule and computational schedule(with maintenance):

The main reasons for the improvements can be seen in Table 7 and Table 8

TABLE 7 Technical statistics of dispatcher schedule and computational schedule

	Coupling times	Decoupling times	Rolling stock swaps
Algorithm	2	3	10
Dispatcher	-	-	-

Table 8: Basic information of used rolling stock units

	Depot	CRH380AL	CRH380A	CRH380B	Utilization
Maintenance	Zhengzhou	0	0	11	61.1%
	Zhengzhoudong	16	0	24	54.8%
dispatcher	Zhengzhou	0	5	5	55.6%
	Zhengzhoudong	22	4	21	64.4%

- Manual schedule: no composition changes at all
- Computational schedule provides an additional level of flexibility
- The rolling stock units with lowest operation cost are considered first in computational schedule

5. Conclusion

Contributions:

- Present a two stage approach for solving the rolling stock scheduling problem with maintenance
- A real-world instance provided by the Zhengzhou HSR network has been used to test the performance of the propose approach. Also the results is verified by dispatchers.

Future study:

- Different timetable for special occasions.
- Compare with other algorithms
- Impact of the new depot location

Thank you for your attention!